

Hydraulic Analysis of Broken-back Culverts



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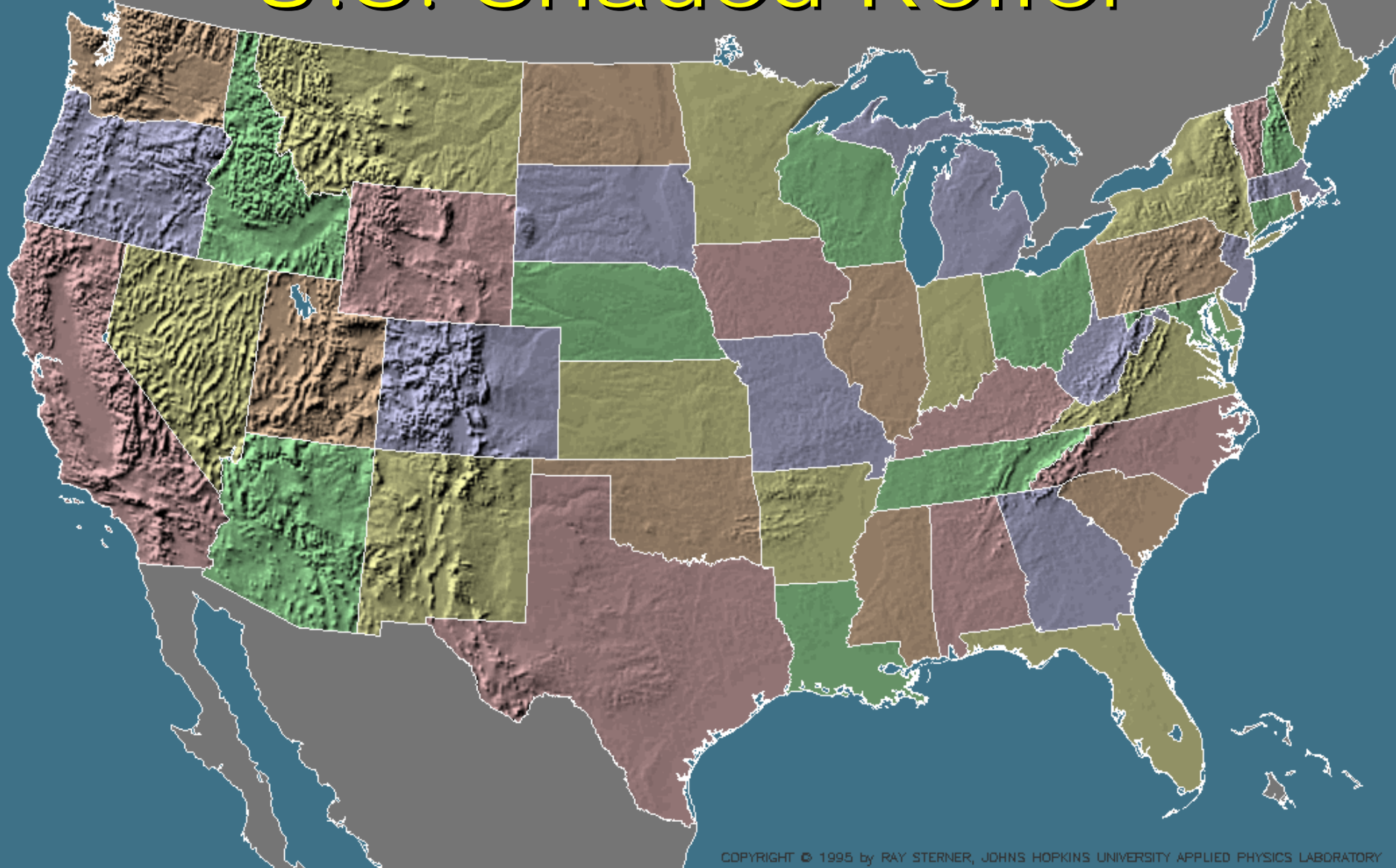
Acknowledgments

- Jeffrey Shafer
- Patrick Flanagan
- Phillip Thompson - FHWA
- http://www.tam.uiuc.edu/courses/TAM235/Lab_manual/Y.pdf
- http://www.mhhe.com/engcs/civil/finnemore/graphics/images/fin32020_ch10/Chapter10partBFiguresX1091/fin32020_1025_JPG.html

Road Map

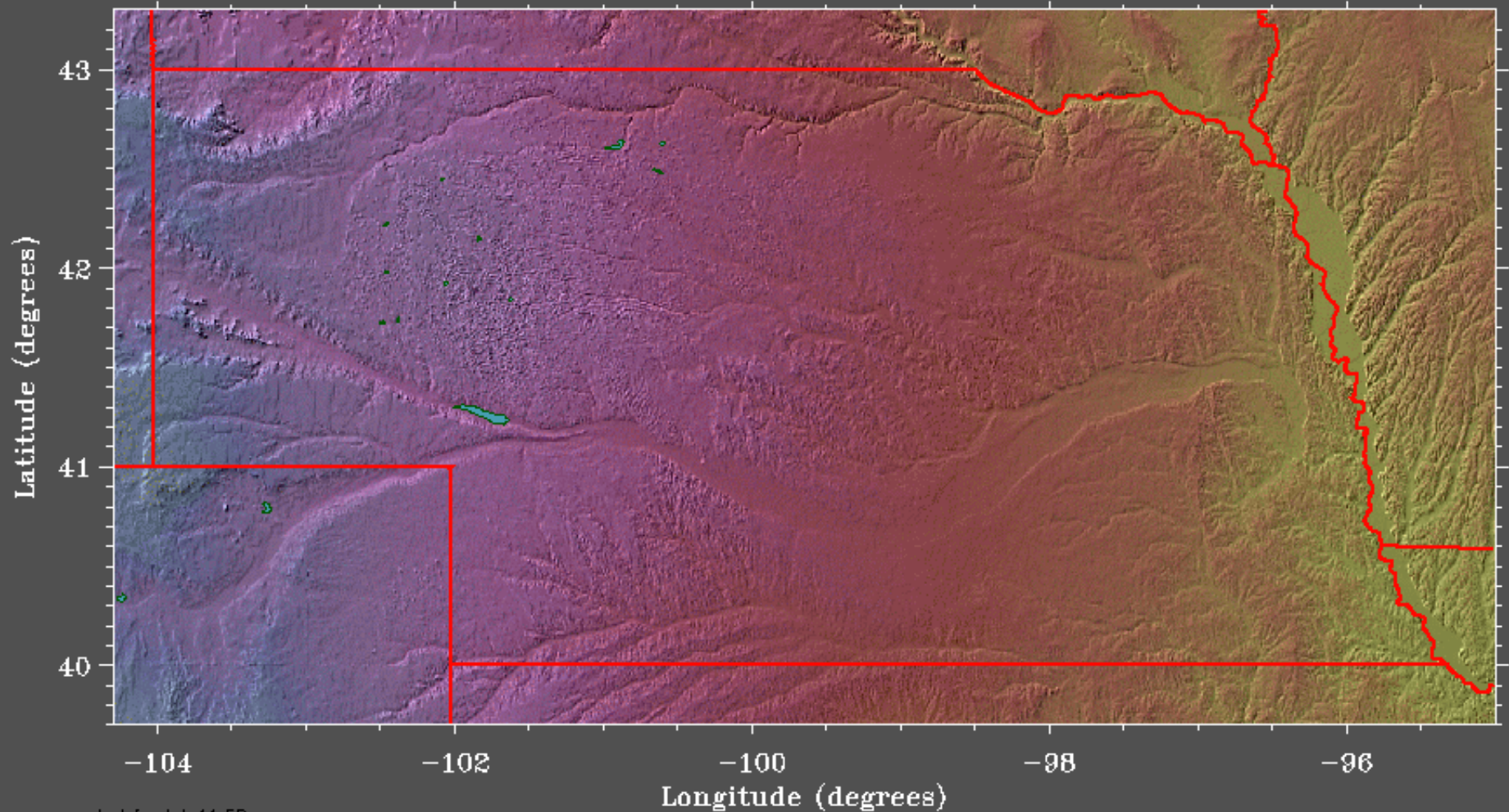
- Description and Need
- Applications
- Basis
- Field Example
- Experimental Program

U.S. Shaded Relief



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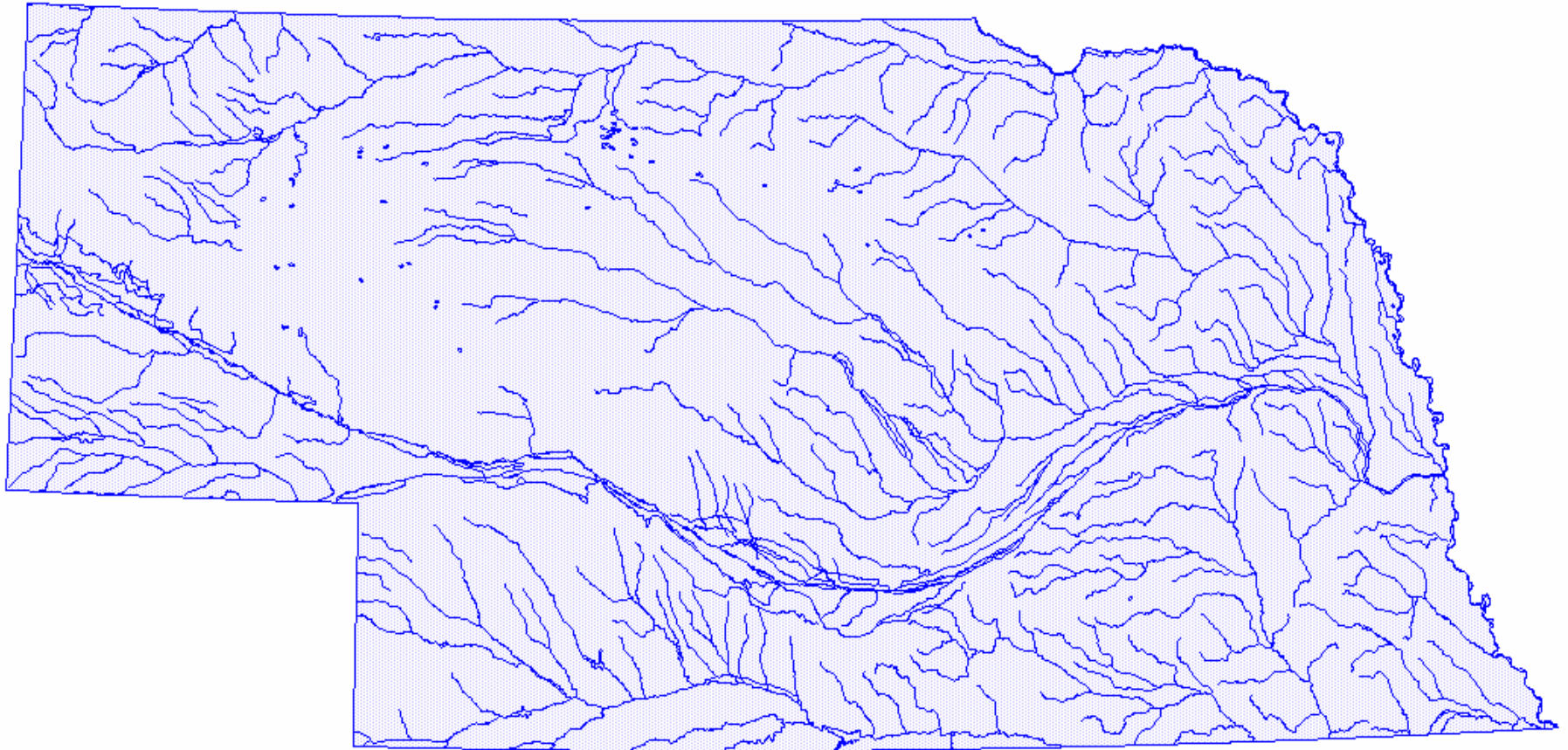
Nebraska Shaded Relief



Shape corrected for lat 41.50

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Nebraska Rivers

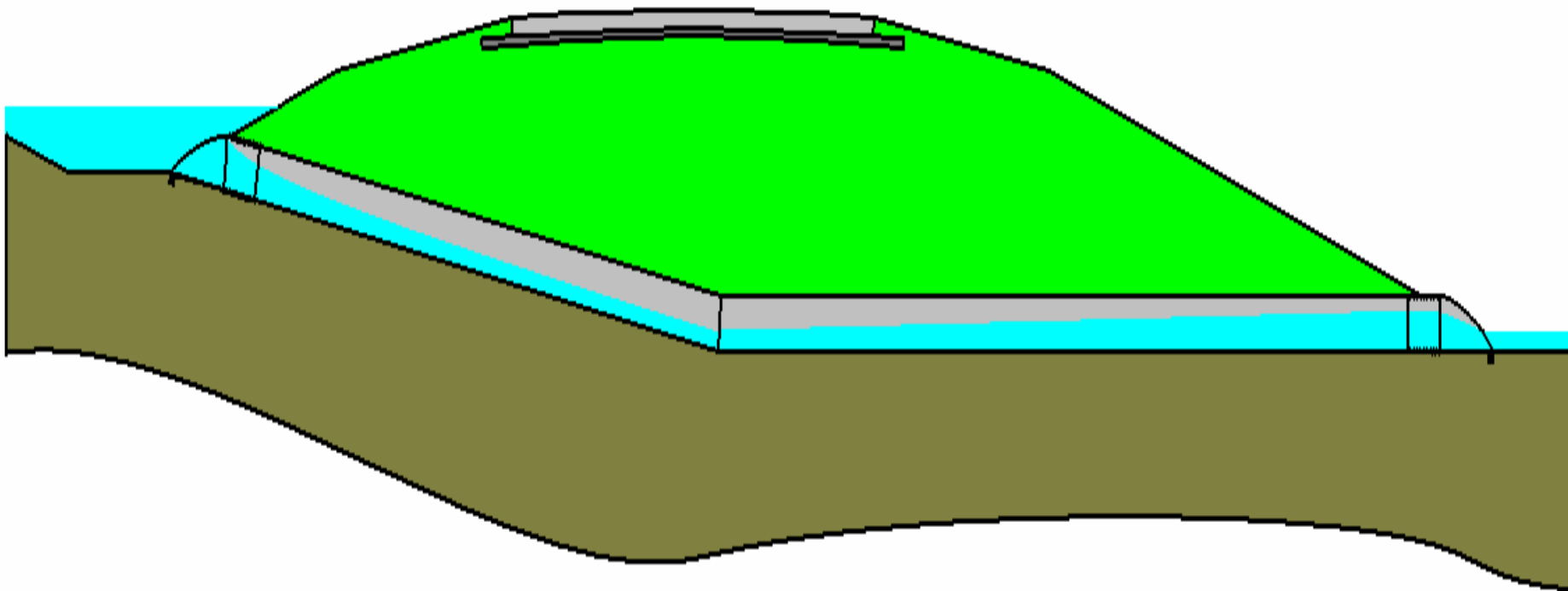




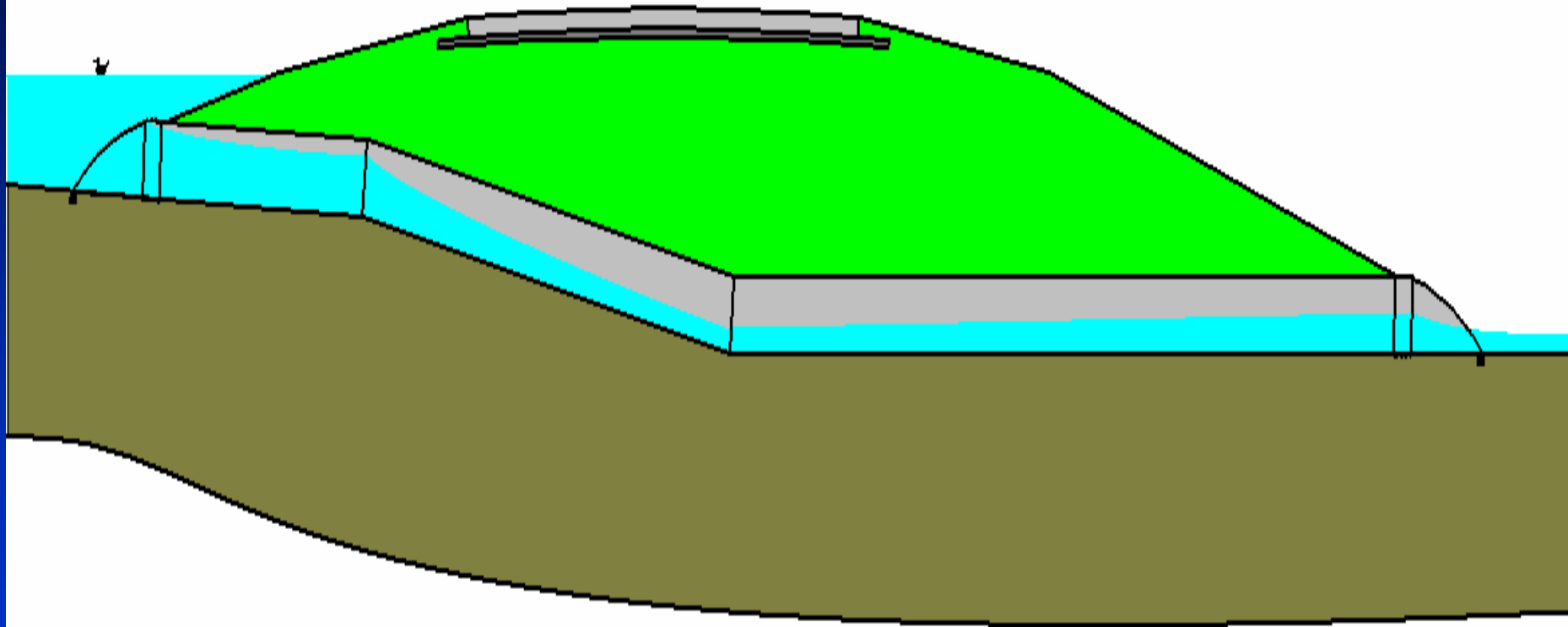
www.hazardnebraska.com



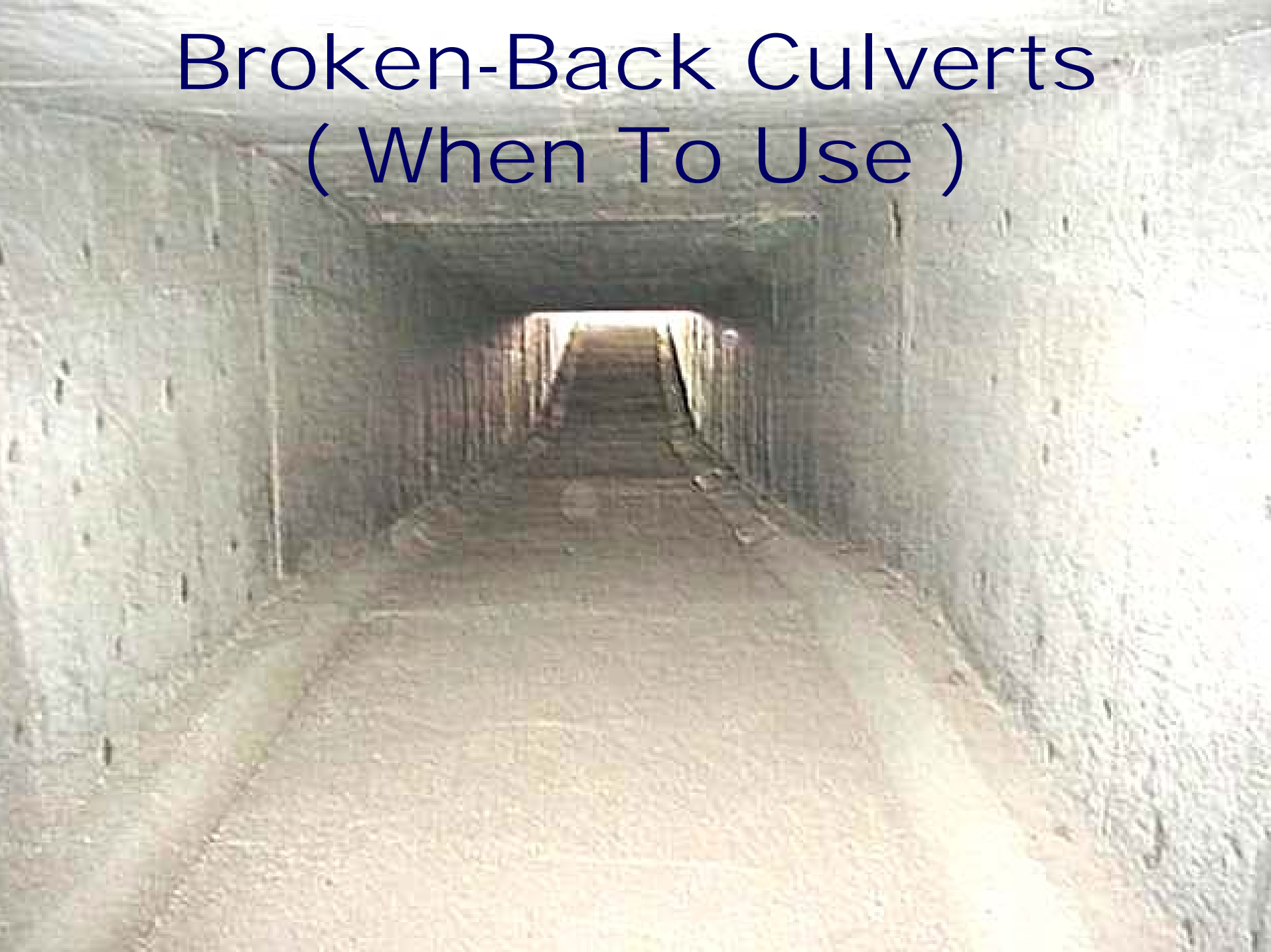
Single Broken-back Culvert



Double Broken-back Culvert



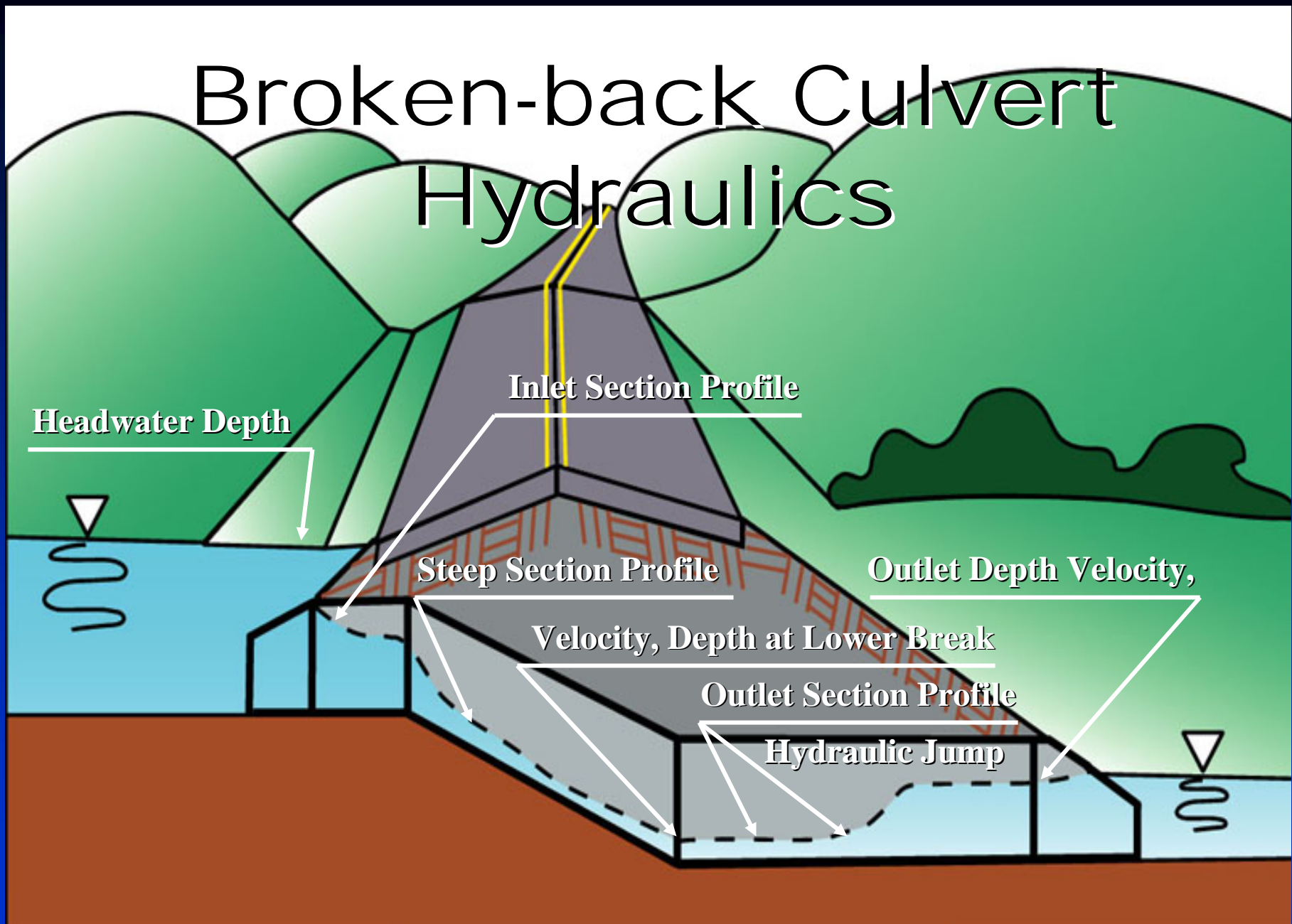
Broken-Back Culverts (When To Use)



Broken-Back Culverts

- Used as grade control structures where there is significant difference between inlet and outlet elevations
- Used as back-slope drains and as “let-down” structures
- Used, in some instances, to minimize excavation quantities
- Used as energy dissipators to help reduce outlet velocities

Broken-back Culvert Hydraulics



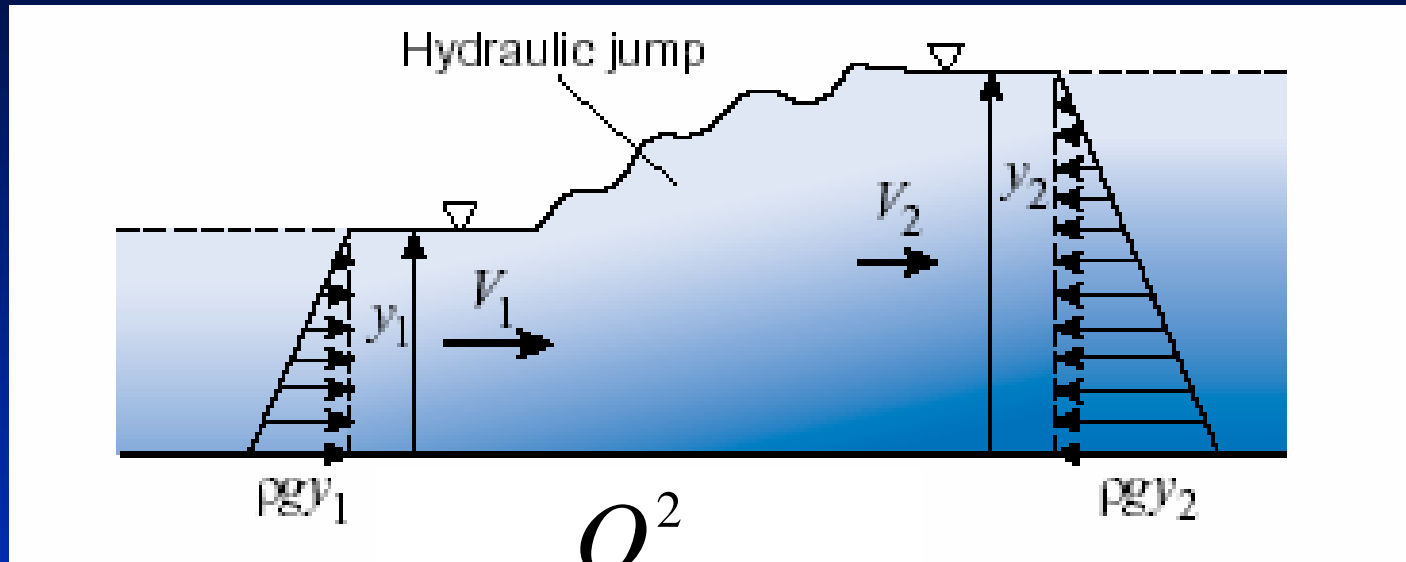
BCAP Usage and Distribution

- At NDOR, BCAP is used by approximately 100 people involved with highway design
- Before being posted on NDOR website, BCAP was distributed to 64 individuals in 22 states
- After posting, BCAP has been downloaded >1000 times (as of the writing of this paper)

Hydraulic Jump Complexities

- Air Entrainment
 - changes specific weight of water
 - transient in nature
- Shape of Jump; Volume
 - momentum analysis completely contains jump
 - does not require details within jump
- Definitions of Where Jump Ends!

Basis for Prediction

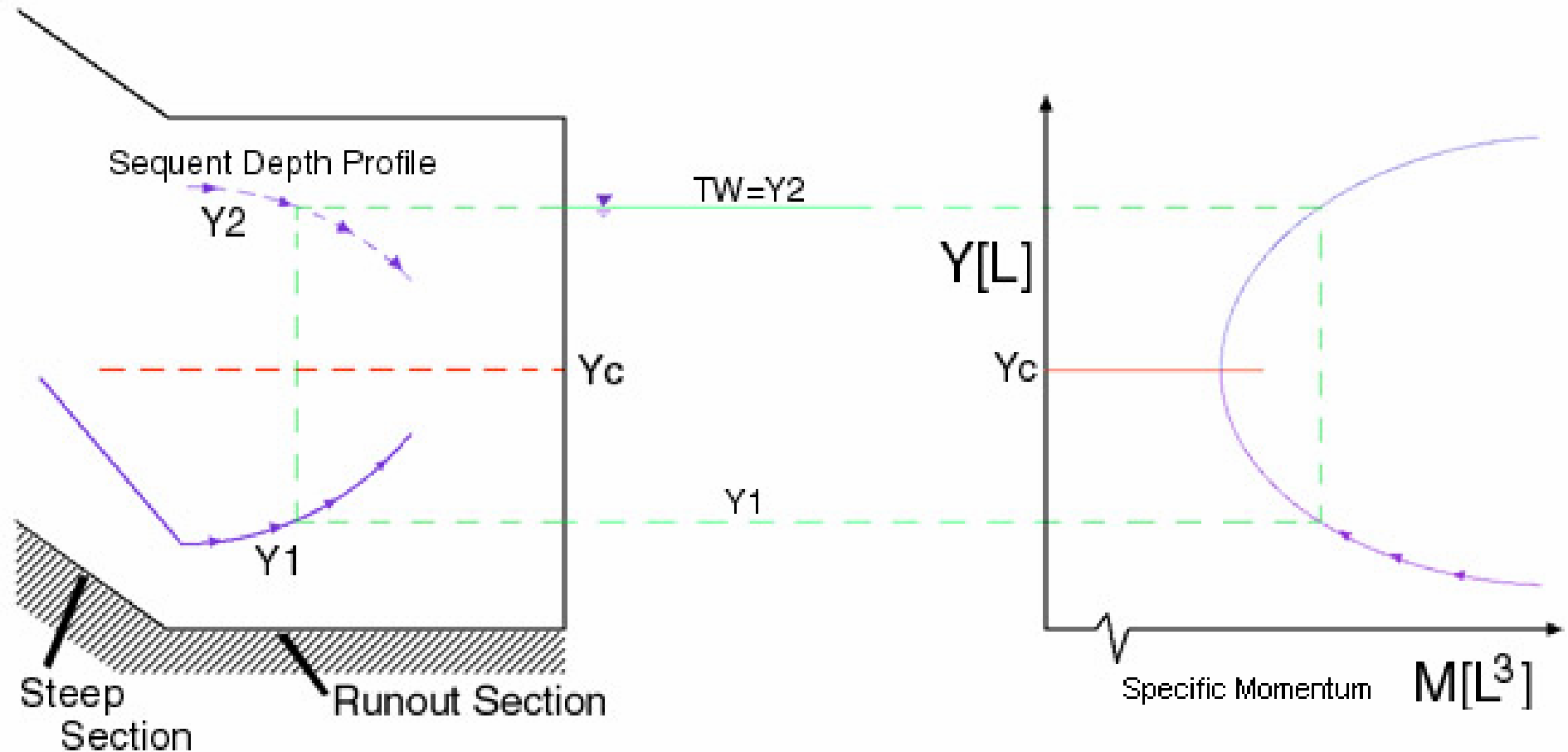


$$F = \frac{Q^2}{gA} + \bar{z}A$$

Inertia term

Pressure term

Momentum Matching



Jump occurs where Y_2 equals TW depth!

Hydraulic Jump Will Occur If...

- The Jump is Completely Contained within the Culvert
- The Tailwater Depth Exceeds the Computed Conjugate Depth
- The Supercritical Froude Number is Less Than or Equal to 1.7

Simplifications

- Neglect Friction Loss within Jump
- Neglect Weight of Fluid
- Tailwater Represents Sequent Depth -
No Upstream-progressing Backwater
Calculations

Hydraulic Algorithms

Parameter	Reference	Equation or notes
Headwater depth	Normann et al. 1985 (2)	Code from HY8 (9)
Critical depth	Pipe: Hager, 1999 (13)	$\text{Sqrt}(Q / \text{Sqr}(\text{grav} * D))$
	Box: French, 1985 (6)	$((Q/B)^2 / \text{grav})^{0.33}$
Sequent depth	Pipe: Straub, 1978 (15)	$(d_c^{1.8}) / (D^{0.73})$
	Box: French, 1985 (6)	$d_1 / 2 (\text{Sqrt}(1 + 8 * Fr_1^2) - 1)$
Jump length	Pipe: Hager, 1992 (12)	$6 * d_2$
	Box: Hager, 1992 (12)	$d_1 * 220 * \tanh((Fr_1 - 1) / 22)$

Hydraulic Algorithms, continued

Parameter	Reference	Equation or notes
Froude number	Pipe: Hager, 1999 (13)	$Q/\text{Sqrt}(\text{grav} * D * d^4)$
	Box: French, 1985 (6)	$Q/A/\text{Sqrt}(\text{grav} * d)$
Tailwater depth and velocity	Manning equation (6)	Code from HY8 (9)
Occurrence of hydraulic jump	Shafer and Hotchkiss, 1998 (1)	Momentum equation
Outlet depth and velocity	Normann et al. 1985 (2)	Continuity equation
Water surface profile	French, 1985 (6)	Energy equation

Broken-back Culvert Analysis Program

- Visual Basic Code
- Available From
 - Nebraska Department of Roads
 - <http://www.dor.state.ne.us/roadway-design>
 - FHWA Hydraulics Engineering Software
 - <http://www.fhwa.dot.gov/bridge/hydsoft.htm>
 - provides a link to the NDOR

Project Data

Project Station or Location Date

Discharge Data

Minimum Discharge cms
Design Discharge cms
Maximum Discharge cms
Number of Barrels

Tailwater Data

☒ Constant Elevation m
☐ Downstream Channel

Channel Shape
Left Side Slope H:1V
Right Side Slope H:1V
Bottom Width m
Diameter m
Bottom Slope m/m

Roughness Coefficient

☐ Irregular Downstream Channel

Create/Edit Irregular Channel Data

Culvert Data

☒ Circular Pipe
Pipe Diameter m
Culvert Material
☐ Concrete Box
Span (per barrel) m
Rise m
Inlet Type
Roughness Coefficient
Outlet Section Roughness Coefficient

Culvert Profile Data

☐ Single Broken-back
☒ Double Broken-back
Inlet Station m
Inlet Elevation m
Upper Break Station m
Upper Break Elevation m
Lower Break Station m
Lower Break Elevation m
Outlet Station m
Outlet Elevation m

Nebraska
Department of Roads

University of Nebraska
Civil Engineering Department

Albrook Hydraulics
Laboratory



Press Button to
Analyze Range of
Discharges



Press Button to
Analyze Design
Discharge

Broken-back Culvert Analysis Program



File Unit Help

Project Data

Project Station or Location Date

Output Data

Head Water Depth	<input type="text" value="1.35"/>	m
Inlet Control Elevation	<input type="text" value="37.77"/>	m
Break Control Elevation	<input type="text" value="37.92"/>	m
Critical Depth	<input type="text" value="0.80"/>	m
Tailwater Depth	<input type="text" value="1.83"/>	m
Hydraulic Jump?	<input type="text" value="YES"/>	
Jump Station	<input type="text" value="48.69"/>	m
Jump Length	<input type="text" value="10.99"/>	m
Outlet Depth	<input type="text" value="1.52"/>	m
Outlet Velocity	<input type="text" value="1.37"/>	m/s
Outlet Froude No.	<input type="text" value="FULL"/>	

Water Surface Profile

Inlet Depth	<input type="text" value="1.27"/>	m	Inlet Velocity	<input type="text" value="1.54"/>	m/s
Upper Break Depth	<input type="text" value="0.80"/>	m	Upper Break Velocity	<input type="text" value="2.56"/>	m/s
Lower Break Depth	<input type="text" value="0.29"/>	m	Lower Break Velocity	<input type="text" value="10.47"/>	m/s
Depth at End of Hydraulic Jump	<input type="text" value="1.52"/>	m	Velocity at End of Hydraulic Jump	<input type="text" value="1.37"/>	m/s
Tailwater Depth (Normal Downstream)	<input type="text" value="1.83"/>	m	Tailwater Velocity (Normal Downstream)	<input type="text" value="0.00"/>	m/s

Culvert Data

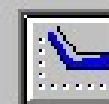
Discharge cms

Shape

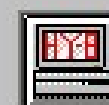
Material

Size - m X m

Inlet Type



Press Button to Plot Profile



Press Button to Enter HY-8 Energy Dissipation

Press to Return to Data Table

File Units Help

Project Data

Project **TRB** Station or Location **WASHINGTON, DC** Date **1/11/03**

Press #
for
Detailed
Culvert
Output

	Discharge	Headwater Depth	Inlet Control Elevation	Break Control Elevation	Critical Depth	Outlet Depth	Outlet Velocity	Outlet Froude Number	Tailwater Depth	Tailwater Velocity	Hydraulic Jump
	cms	m	m	m	m	m	m/s		m	m/s	
0	1.000	1.00	37.24	37.58	.51	1.52	.55	FULL	1.83	.00	YES
1	1.400	1.11	37.41	37.68	.60	1.52	.77	FULL	1.83	.00	YES
2	1.800	1.20	37.55	37.78	.68	1.52	.99	FULL	1.83	.00	YES
3	2.200	1.28	37.68	37.86	.75	1.52	1.21	FULL	1.83	.00	YES
4	2.500	1.35	37.77	37.92	.80	1.52	1.37	FULL	1.83	.00	YES
5	3.000	1.44	37.92	38.02	.88	.42	7.29	4.4	1.83	.00	NO
6	3.400	1.52	38.04	38.09	.94	.45	7.59	4.4	1.83	.00	NO
7	3.800	1.59	38.16	38.17	.99	.47	7.88	4.4	1.83	.00	NO
8	4.200	1.71	38.28	38.25	1.04	.49	8.18	4.4	1.83	.00	NO
9	4.600	1.84	38.42	38.33	1.09	.52	8.39	4.4	1.83	.00	NO
10	5.000	1.99	38.56	38.42	1.14	.54	8.55	4.4	1.83	.00	NO

Press Button for
Headwater Rating
CurvePress Button for
Outlet Depth
Rating CurvePress Button for
Outlet Velocity
Rating Curve

Press to Return to Input Form

Project: TRB

Location: WASHINGTON, DC

Date: 01/11/2003

Circle Pipe Culvert

Diameter=1.524 m

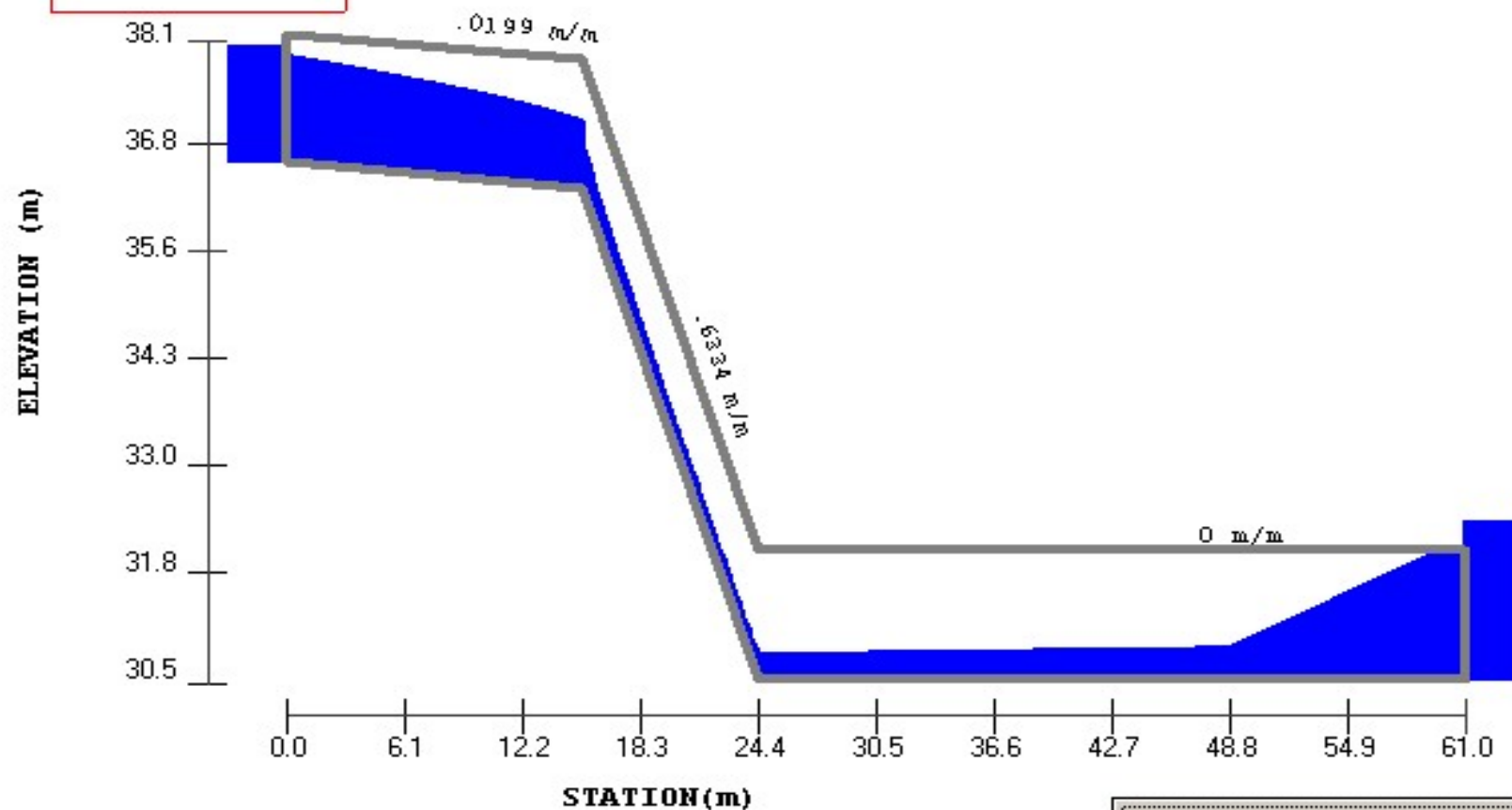
Culvert Material: Concrete

Inlet Type

Flared End Section

Rough. Coeff.= 0.012

Outlet Sec. Rough. Coeff.= 0.012

Q = 2.5 cms

Source: UNTITLED

Press to Return to Output Form

Project: TRB

Location: WASHINGTON, DC

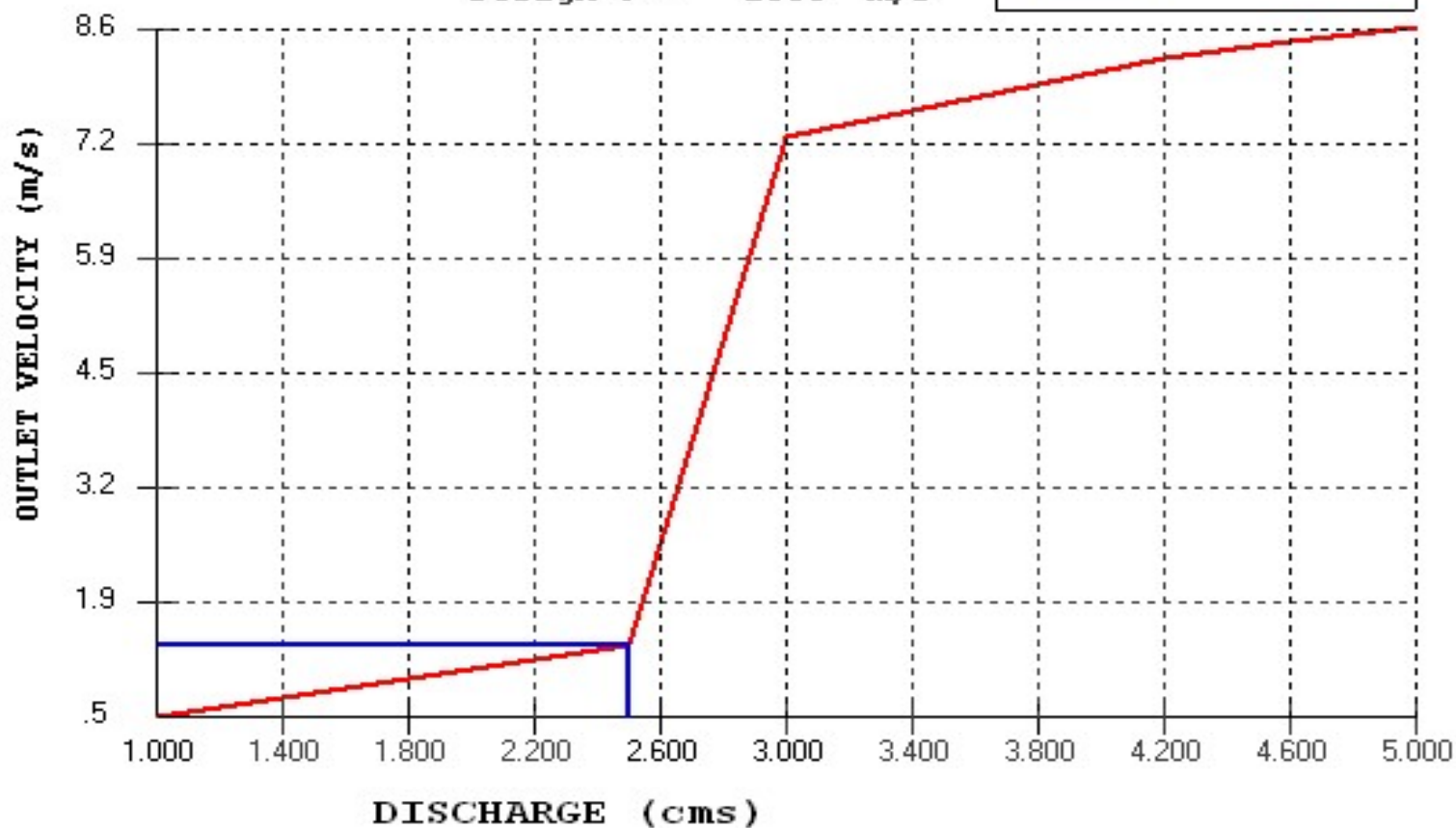
Date: 01/11/2003

DISCHARGE vs. OUTLET VELOCITY

Design Q = 2.500 cms

Design V = 1000 m/s

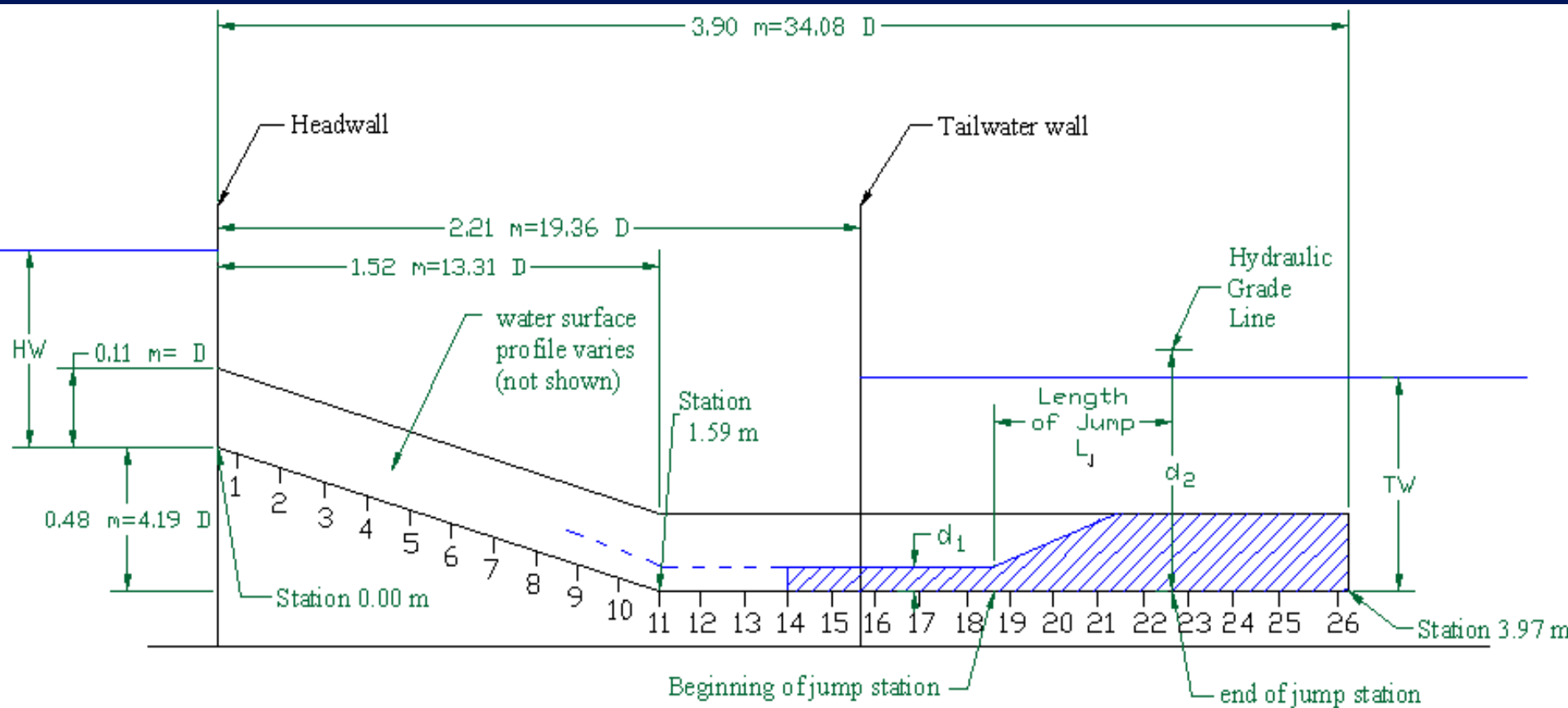
Design Value



Experimental Program

- Acrylic pipe and box
- Single broken-back
- Square edge with headwall entrance
- Adjust discharge and tailwater elevation

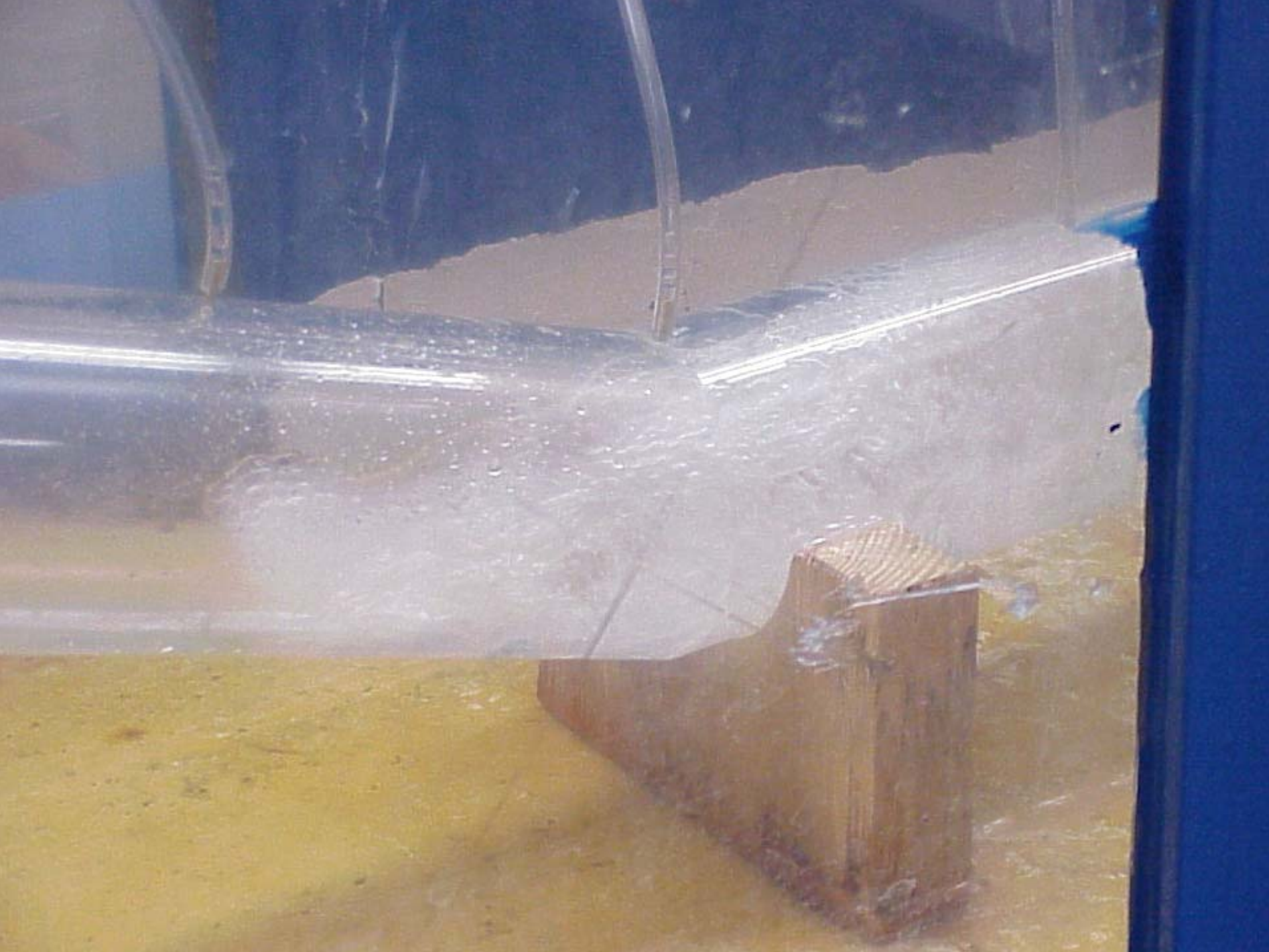
Experimental Setup

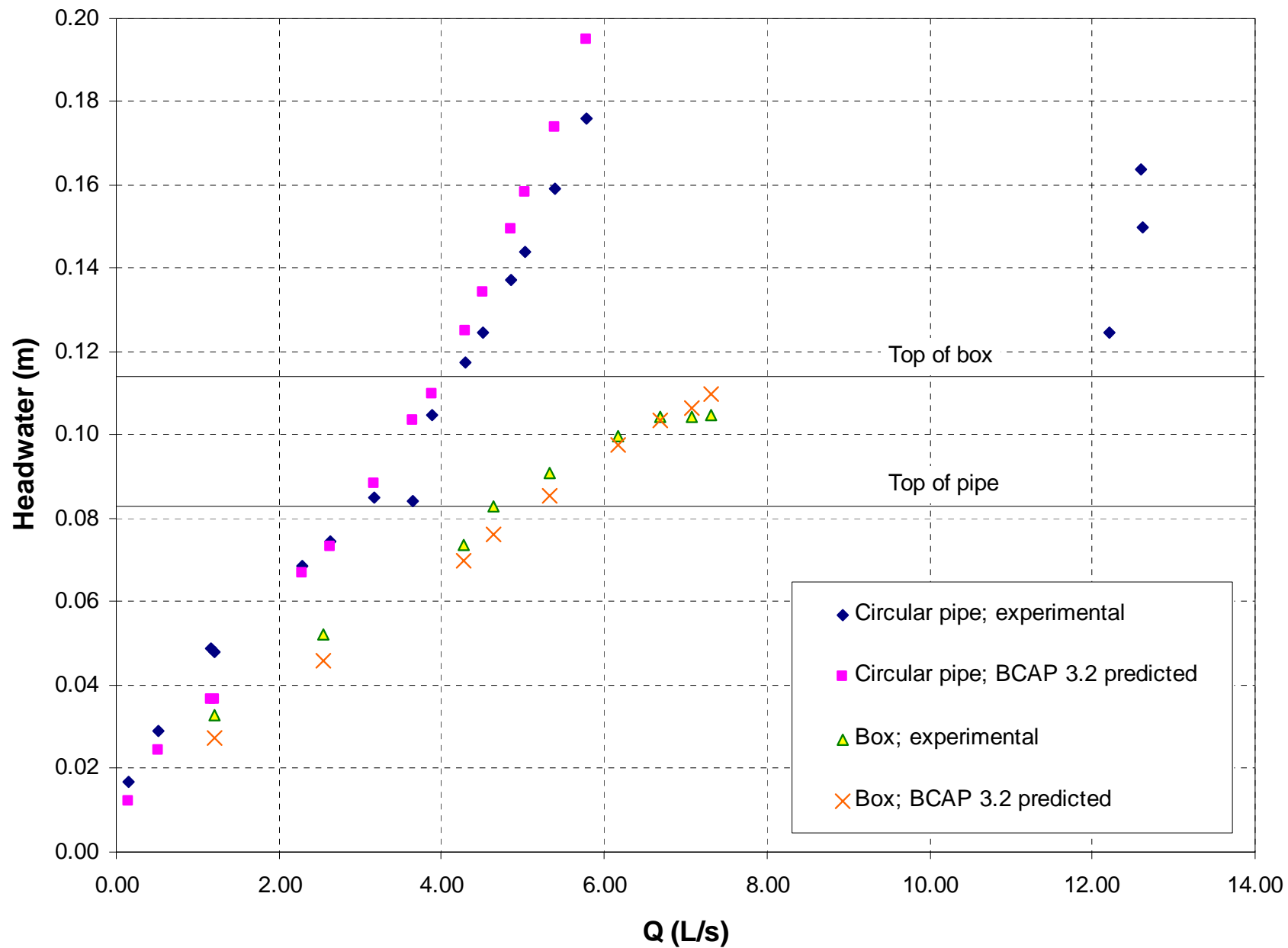


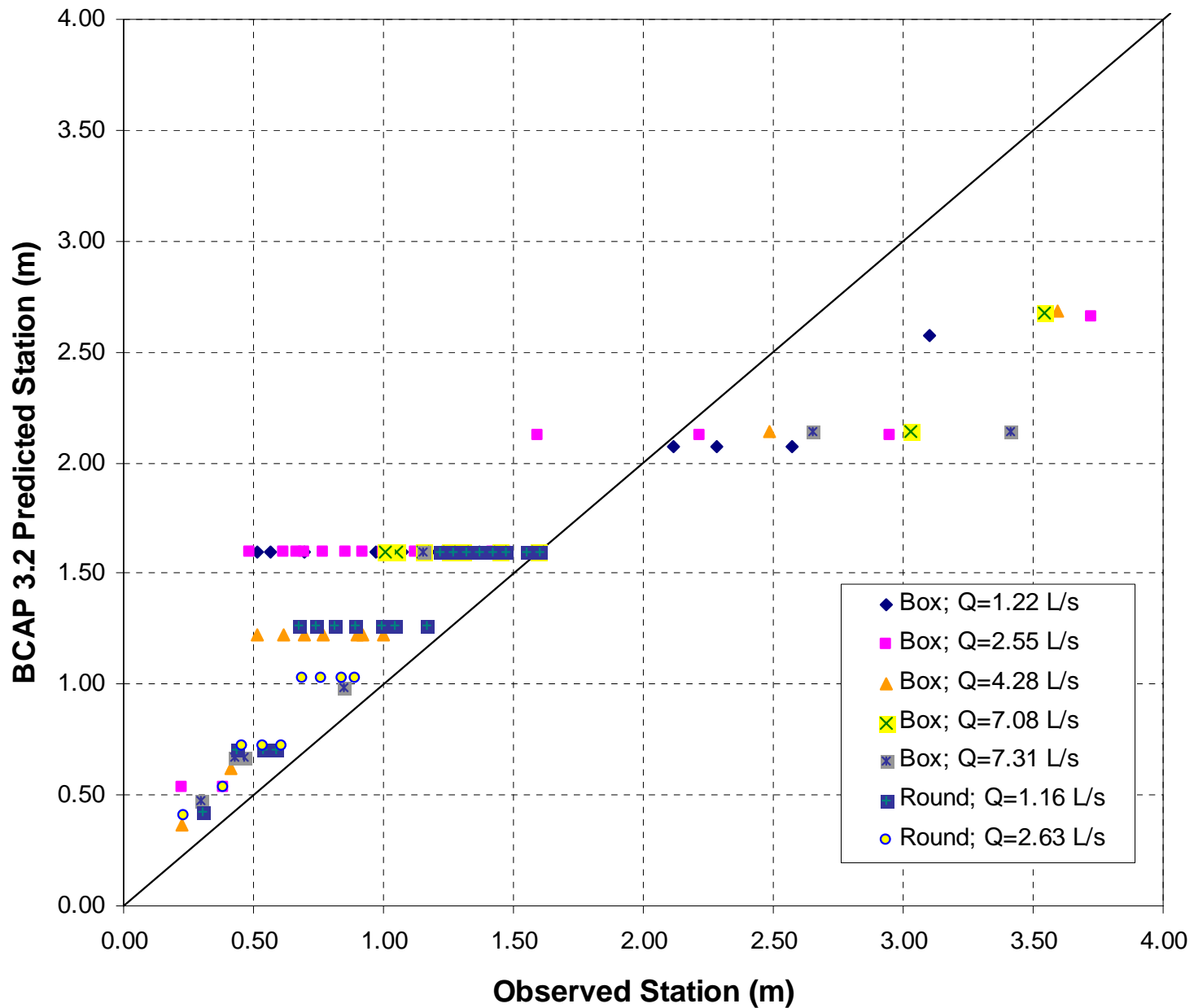


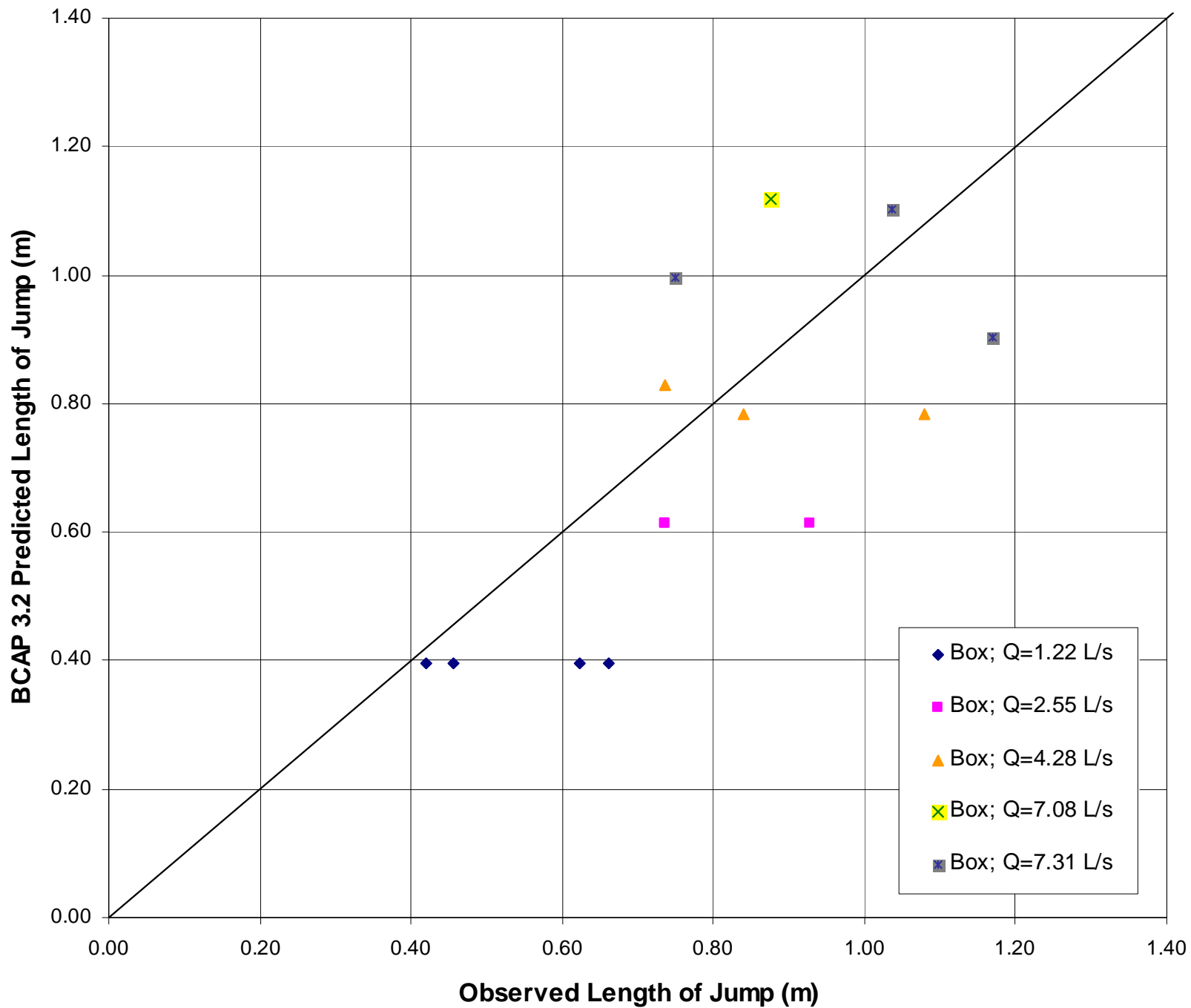












Conclusions

- BCAP research and computer program have solved the mystery of broken-back culvert hydraulics
- BCAP has helped to change policy regarding pipe materials
- Future enhancements to BCAP are being considered
- BCAP research has further advanced the State-of-the-Art for culvert hydraulics